**Radioactivity - Radionuclides - Radiation**
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# Case Study: Verification of Spent Fuel Elements in Ponds

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# Decay Ponds

- After irradiation in a reactor, the spent fuel assemblies are placed in a pond for decay of the short-lived fission products, for a period of about 6 years

- These ponds must be inspected regularly in order to avoid any material diversion, verify the burn up and the plutonium quantity

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# Detection methods

- A fuel assembly is remotely extracted from the rack, while still in the pond. A remote fork detector dives and measures the radiation emitted by the spent fuel rod.
- The fork detector is made of an ionization chamber for γ detection and 2 He tubes for neutron detection per arm. A CdZnTe γ spectrometer can also be used

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# Detection methods

- Our case study: the facility has declared a 4.2% enriched fuel irradiated in PWR up to 50 GWd/t and decaying in ponds for 2.8 years

- Step 1: Verification of the burn up of the fuel element via γ spectrometry
- Step 2: Confirmation via neutron measurements
- Step 3: Calculation of the corresponding plutonium mass

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# γ measurements

- Step 1: In order to verify the burn up of the fuel element, the ratio between $^{134}Cs$ and $^{137}Cs$ is measured via γ spectrometry

- Number of counts:

  $N_{Cs137}=1.17x10^3$ counts/s for the 662 keV line

  $N_{Cs134}=1.06x10^3$ counts/s for the 605 keV line

- What is the mass ratio of Cs137 and Cs134?

  - The total relative activity of Cs137 and Cs134 must be calculated
    - Use the Data Sheets
  - The mass corresponding to such activity must be calculated
    - Use the Decay Module

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# The total activity is: A=N/BR

## To find the branching ratio: Use the Data Sheet Module

nuclides.net

**$^{137}$Cs** **DataSheet**

| Print | FactSheets | Notes | Averaged Cross sections |
|---|---|---|---|

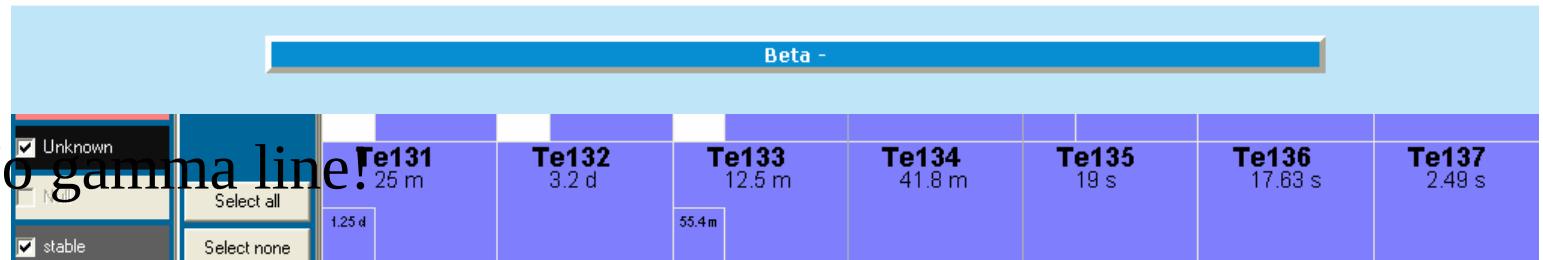
| Mass Excess | Mass | Half-life | Abundance |
|---|---|---|---|
| -86551.1 (± 30) keV | 136.907083470 (± 3221) u | 30.07 (± 3) y | - |

| Spin | Parity | Binding Energy |
|---|---|---|
| 7/2 | + | 8.389 MeV |

| Type of decay | Branching ratio | Decay Energy,Q(MeV) | Daughters |
|---|---|---|---|
| ß- | 9.46E-01 | 0.51 | 56 Ba 137m |
| ß- | 5.40E-02 | 1.17 | 56 Ba 137 |

| Mean Decay Energies | Alpha(MeV) | Electron(keV) | Photon(keV) |
|---|---|---|---|
| | 0 | 186 | 0.04 |

| Effective Dose Coefficient Ingestion (Sv/Bq) | Effective Dose Coefficient Inhalation (Sv/Bq) | Reference Annual Dose Workers | Reference Annual Dose Public |
|---|---|---|---|
| 1.3000E-08 | 3.900E-08 | 20 mSv | 1 mSv |




No gamma line!

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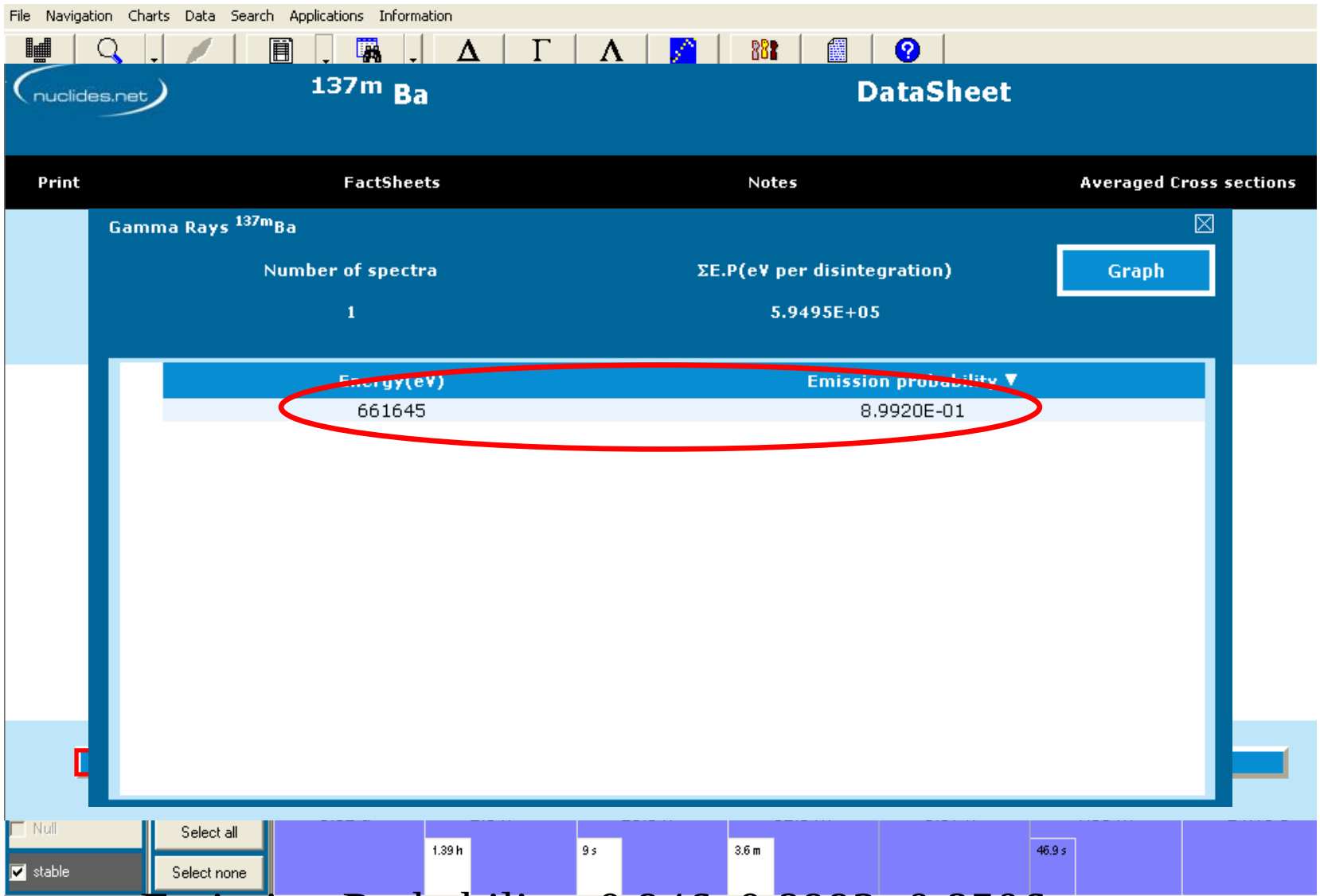


Emission Probability=0.946x0.8992=0.8506

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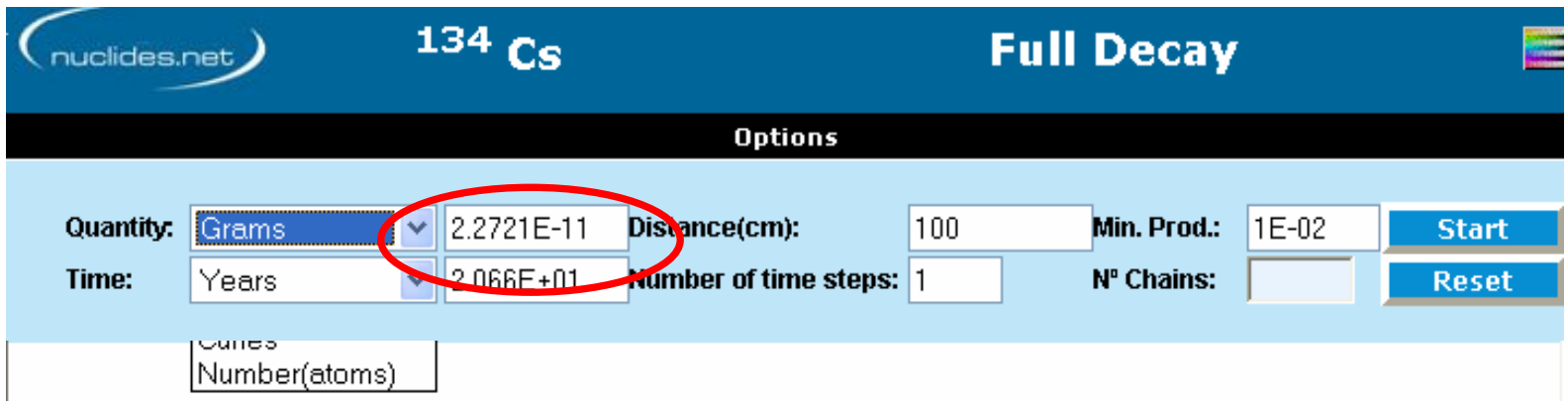
| Isotop | Counts | γ line (keV) | EP (%) | Activity (Bq) | Mass (g) |
|---|---|---|---|---|---|
| Cs134 | 1.06E+03 | 605 | 97.54 | 1.087E+03 | 2.27E-11 |
| Cs137 | 1.17E+03 | 662 | 85.06 | 1.376E+03 | 4.28E-10 |

Mass ratio of Cs134/Cs137 is 0.0530

To calculate the mass from the activity use the decay module !



# KORIGEN calculations

- The measured mass ratio of Cs134 and Cs137 is compared to a calculation of this ratio with KORIGEN, Isotope generation and depletion code, that will be integrated to the next version of Nuclides.net

- The first calculation is made assuming the declared value correct, i.e. 4.2% enriched fuel, burn up 50 GWd/t, 2.8 years cooling

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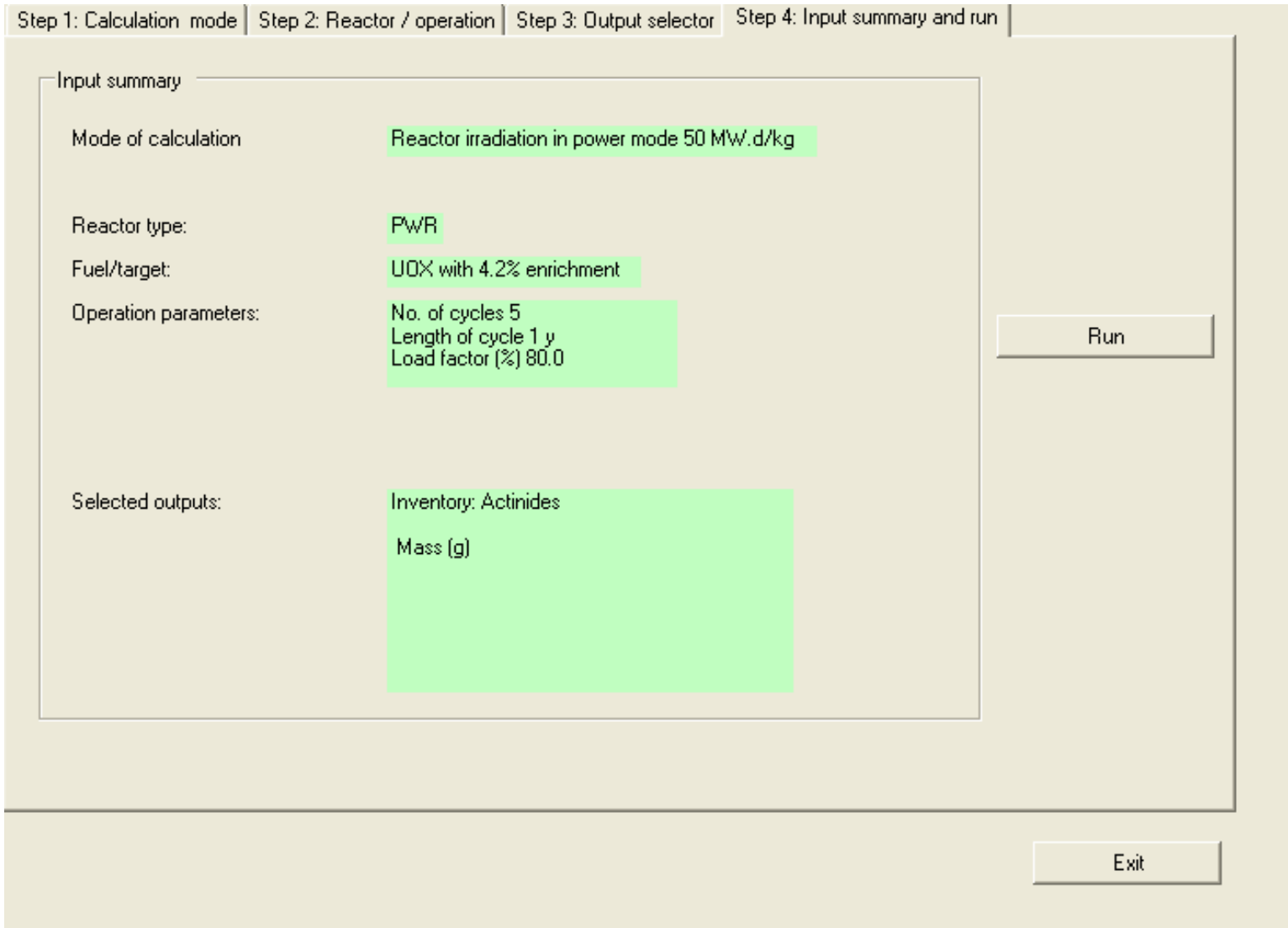


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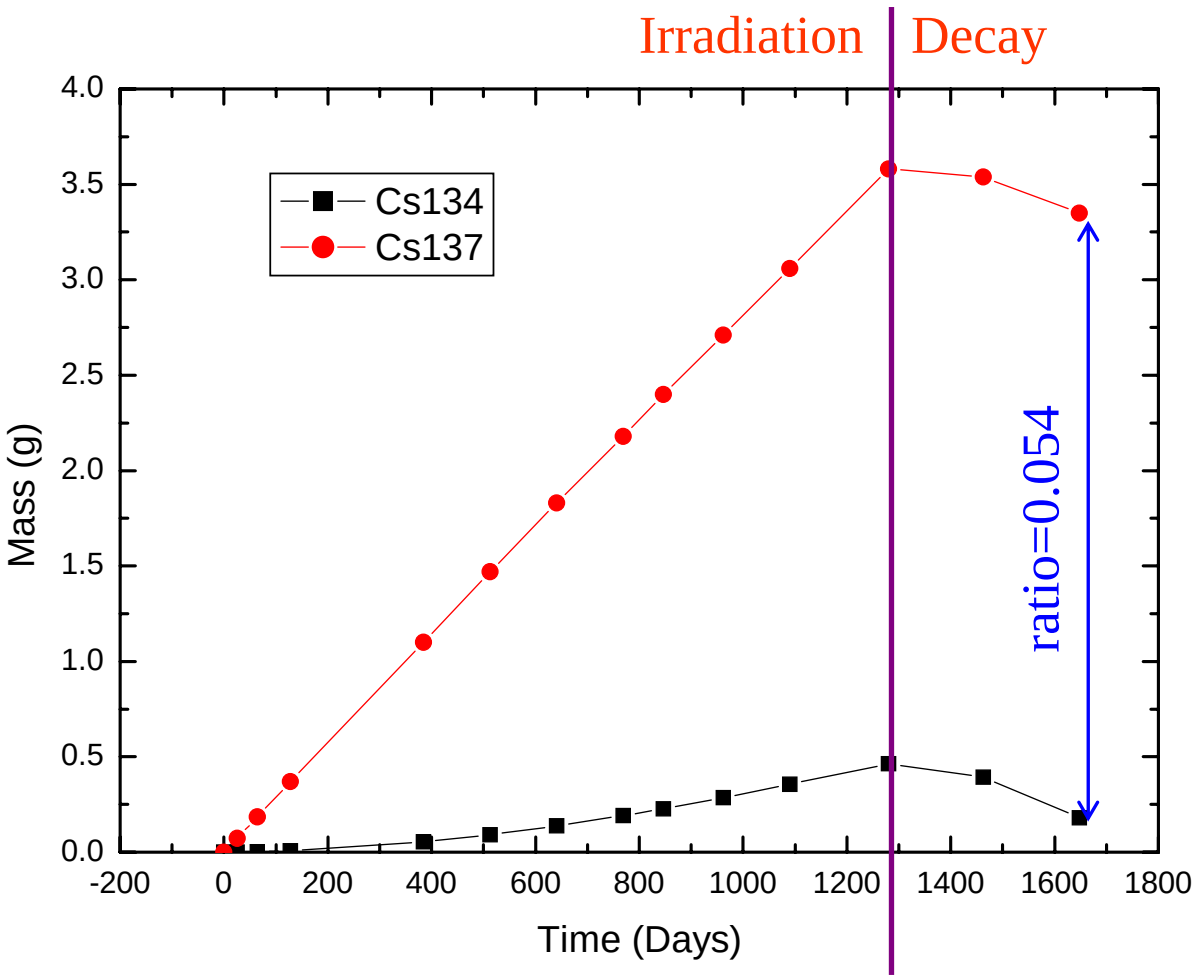
With KORIGEN output we can plot the mass evolution (buildup during irradiation and decay in ponds) of the Cs134 and 137




Calculation and measurement are in agreement

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# Neutron measurements

- Step 2: Neutron measurements. The neutron source of the spent fuel assembly in the pond is mainly due to the spontaneous fission of Cm244.

- Number of counts: $N=1.06 \times 10^5$ n/s
- Knowing that
  - Calibration efficiency 1%
  - Spent fuel rod is 4m long, and the detector is sensitive on 10 cm only
- Find the total neutron source and compare to the calculation (KORIGEN module)

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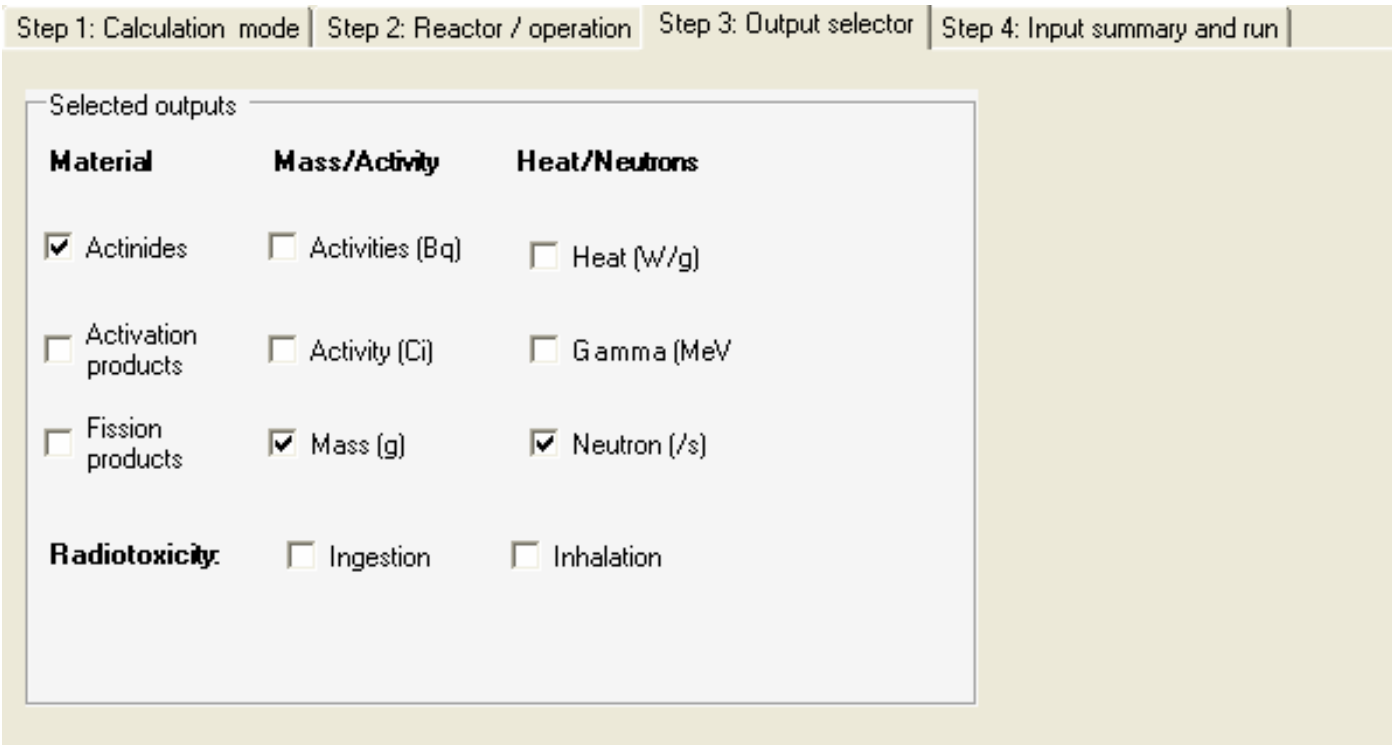
- The total neutron source is:

$$N_{Total}=N/(\varepsilon x(L_{assembly}/L_{detector}))=4.25x10^{8}n/s$$

- The spontaneous neutron source can be calculated by KORIGEN

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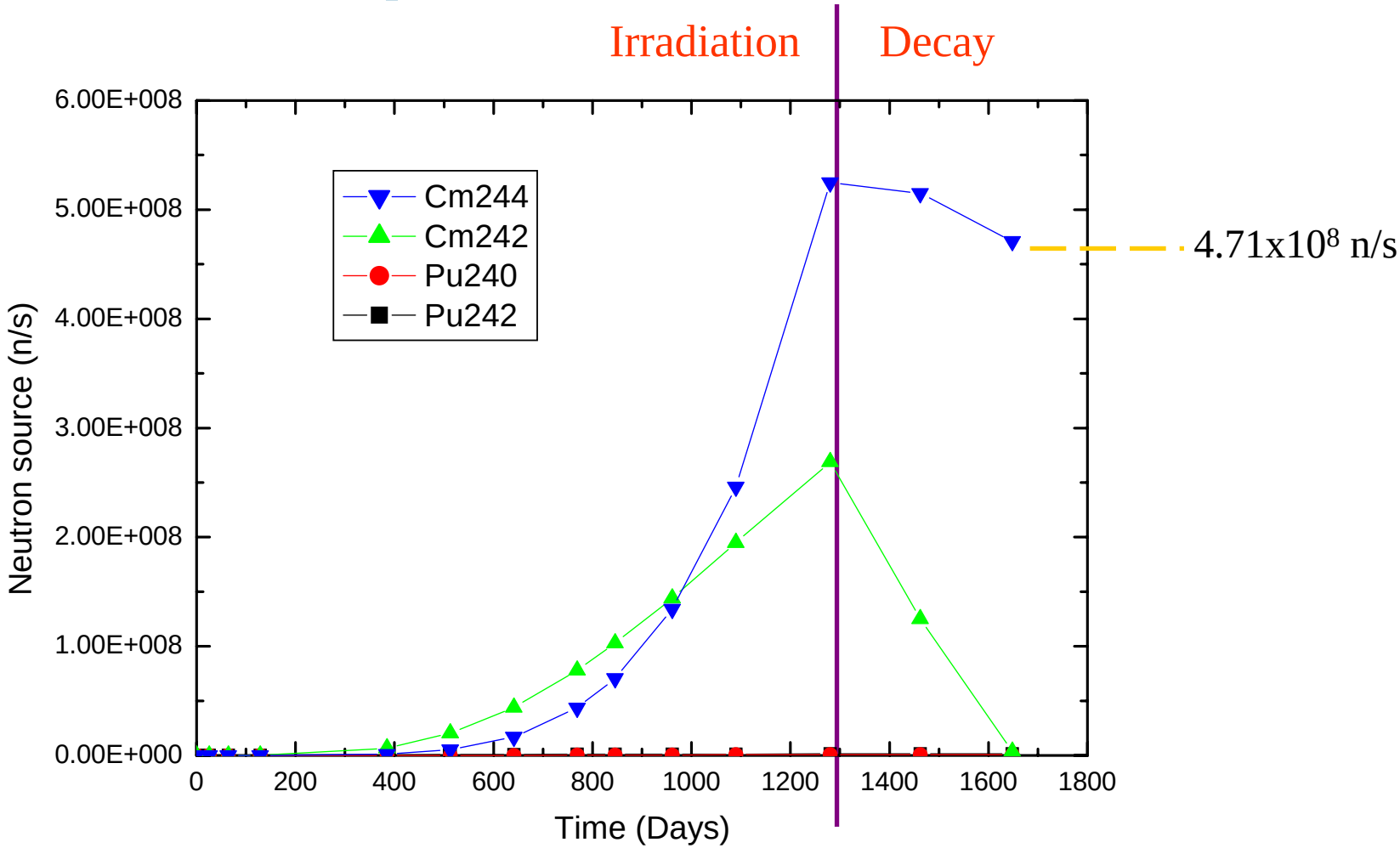
- KORIGEN calculation verifies that it correspond to the declared burn up




Measured $4.25 \times 10^8$ n/s

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# Plutonium Mass Calculation

- Step 3: The burnup and decay time being verified, the plutonium mass can be computed with KORIGEN

- The Mass of Plutonium in one fuel assembly (50GWd/t burnup, 2.8 years decay) is:

| | Mass (g) |
|---|---|
| PU238 | 1.69E+02 |
| PU239 | 3.10E+03 |
| PU240 | 1.43E+03 |
| PU241 | 8.00E+02 |
| PU242 | 4.50E+02 |

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